Report Out of the C4I Study Group

Donald H. Timian
Computer Associates
5502 Leesburg Pike, Suite 1200
Falls Church, VA 22041
(703) 824-4020
donald.timian@ca.com

Dr. Michael R. Hieb
IITRI/AB Technologies Group
1901 N. Beauregard Street
Alexandria, VA 2231
(703) 933-3376
mhieb@iitri.com

Joseph Lacetera
Monmouth Science and Technology, Inc.
PMB 180, 328 South Main Street
Bel Air, MD 21014
(443) 253-9060
lacetera@msti-b.com

Dr. Andreas Tolk
Industrieanlagen-Betriebsgesellschaft mbH.
(IABG)
Einsteinstr. 20
D-85521 Ottobrunn, Germany
tolk@iabg.de

Chris Wertman
Booz-Allen & Hamilton
4301 N. Fairfax Drive, Suite 200
Arlington, VA 22203
(703) 908-4441
wertman_chris@bah.com

Kevin Brandt
The MITRE Corporation
P.O. Box 51037
Hampton, VA 23651
757-726-6896
brandtk@mitre.org

Keywords:
C4I, C4ISR, HLA, JTA, M&S, C4ISR-to-Simulation FOM, M&S-to-C4I Interoperability, C4I/M&S TRM, SISO M&S-to-C4I Interoperability SG, SIMCI, and SG-C4I

ABSTRACT: *Simulation interfaces to Command, Control, Communications, Computers, Intelligence, Security, and Reconnaissance (C4ISR) systems are essential to support: Simulation Based Acquisition (SBA); the development of Doctrine, Tactics, Techniques, and Procedures (DTTP); "Train as you fight;" Embedded Training (both individual and collective); Course of Action Development and Analysis; Mission Planning and Rehearsal; and Execution Monitoring. Modeling and Simulation (M&S) systems have standardized on certain protocols and architectures for interoperability, such as the High Level Architecture (HLA). Within the Department of Defense (DoD), the C4ISR community is also moving to standardize on the Joint Technical Architecture (JTA) and the Defense Information Infrastructure Common Operating Environment (DII COE). These interoperability efforts, as well as efforts within the DoD and the international community to standardize message formats and develop common M&S and C4I data models may – if the appropriate standards are identified and developed – significantly enhance efforts to link M&S and C4ISR systems. However, a robust "two-way" dialog is required.*

In order to assess "where we are and where we need to go" the Simulation Interoperability Standards Organization (SISO) charted an M&S-to-Command, Control, Communications, and Intelligence (C4I) Interoperability Study Group to: 1) provide background and current information on C4ISR and simulation interoperability efforts; 2) provide a standards-based assessment of past and current interoperability efforts; and 3) make recommendations on how the Simulations Interoperability Workshop (SIW) C4I Forum should proceed with standards development activities. This paper is the report of the M&S-to-C4I Interoperability SG. It discusses "where we have been," "where are we now," "where we should go," and "how do we get there." While the authors have collated submissions and edited this report, in truth it is the result of more than a dozen direct contributions in the form of draft sections and the indirect contributions of the more than one hundred subscribers to the SG-C4I reflector.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **JUN 2001**	2. REPORT TYPE	3. DATES COVERED **00-00-2001 to 00-00-2001**
4. TITLE AND SUBTITLE **Report Out of the C4I Study Group**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Computer Associates,5502 Leesburg Pike Suite 1200,Falls Church,VA,22041**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES **The original document contains color images.**		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**		**31**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

1. Introduction

"The Simulation Interoperability Standards Organization (SISO) is dedicated to the promotion of Modeling and Simulation (M&S) interoperability and reuse for the benefit of diverse M&S communities, including developers, procurers, and users, world-wide" [44]. Through the Simulation Interoperability Workshops (SIW), SISO provides a forum for the interchange of new ideas and concepts across a broad M&S community and lays the groundwork for subsequent standards development. As an intermediate step between the papers presented at the semi-annual workshops and standards development, SISO charters Study Groups (SGs) to look at specific M&S issues that may ultimately bear on the development of standards. A key issue for both the M&S and the Command, Control, Communications, Computers, Intelligence, Security, and Reconnaissance (C4ISR) communities is the interoperability between C4ISR systems and simulations. To address this issue, SISO chartered a SG for M&S--to-C4I Interoperability (SG-C4I). This paper is the final report out of the C4I Study Group. It discusses *where we are*, *where we should go*, and recommends *how to get there*.

1.1 Purpose of the SISO C4I Study Group

The SISO M&S-to-C4I SG was chartered in March 1999. The Study Group's Terms of Reference [43] or goals, as specified by SISO's Executive Committee, are to:

- Recommend an approach or approaches that will support an appropriate and sufficient level of interoperability between C4ISR systems and High Level Architecture (HLA) based simulations;
- Deliver a report which characterizes the current "state of the art" of M&S-to-C4I interoperability; and
- Develop a categorical bibliography and a partial C4I/M&S interoperability lexicon. (Both to be published separately.)

1.2 Structure of this Report

To satisfy the Study Groups goals, this report will:

- Provide background and current information on C4ISR and Simulation Interoperability efforts;
- Provide a standards-based assessment of past and current interoperability efforts; and
- Make recommendations on how the Simulation Interoperability Workshop (SIW) C4I Forum should proceed with M&S-to-C4I interoperability related standards development.

To coherently build the case for standards activity recommendation(s) this report is organized to answer the following questions:

Where have we been? In Sections 2.1, the report contains a synopsis of the history of U.S. simulation and C4ISR interoperability in order to provide the reader with a contrast to the current state of interoperability between the two domains.

Where are we now? In the remainder of Section 2 and Section 3 the report describes a number of representative ongoing efforts and concepts.

Where should we go? In Section 4 we provide a vision on how to achieve M&S-to-C4I interoperability and a C4I/M&S Technical Reference Model (TRM) is described and recommended for consideration by the M&S community.

How do we get there? In Section 5 a set of recommendations on how to proceed are presented.

2. Background and Issues

Motivation for improving the interoperability between simulations and C4ISR systems include:

- Simulation Based Acquisition (i.e., Requirements Development and Analysis, Testing, and Training)
- Development of Doctrine and Tactics Techniques, and Procedures (DTTP)
- *Train as you fight;*
- Embedded Training (both individual and collective)
- Course of Action Development and Analysis
- Mission Planning and Rehearsal; and
- Execution Monitoring.

The Department of Defense (DoD) has undertaken efforts to increase interoperability – via the High Level Architecture (HLA) – of C4ISR systems to simulations. For example, the Army has an ongoing project to draft a Capstone Requirements Document for a Simulation-to-C4I Interface (SIMCI) that will define the "high level interface requirements for simulations (tactical, training, analytical, and testing) that will interact with C4ISR systems of the future" [14].

However, while the M&S community is moving on a path towards standardizing interfaces on emerging HLA approaches, the DoD C4ISR community is moving to standardize on the Joint Technical Architecture (JTA) [26] and the Defense Information Infrastructure Common Operating Environment (DII COE) [9]. As noted in Flournoy [17], Hieb and Staver [21], and Ressler et al [40], over the last decade, uncoordinated standards for M&S-to-C4I interoperability have been and are currently being developed by both communities. In addition, Flournoy [17] also discusses the implications of these efforts on M&S-to-C4I interoperability and states that standardization, occurring within both communities, raises hopes that the number of M&S-to-C4I interoperability needs can be reduced to a handful of connection solutions at the infrastructure level between the COE and HLA-compliant Run Time Infrastructures (RTI).

Several factors influence the viability of linking the M&S and C4ISR domains [2]. However, an absolutely *seamless* interface between these two domains is neither feasible (as described below) nor desirable (as described in Section 2.3).

- First, applicable standards (i.e., HLA, JTA, DII COE) in both domains continue to evolve rapidly. Viable interfaces require absolute synchronization at intermediate stages of development of both the standards and the effective implementations. Uncoordinated development schedules challenge interoperability solutions attempting to be sufficiently flexible to accommodate drifting standards.
- Second, via the Levels of Information Systems Interoperability (LISI) model (see Figure 1; http://www.c3i.osd.mil/org/cio/i3/awg_digital_library/index.htm), the Defense Information Systems Agency (DISA) has embraced the fact that interoperability between specific C4ISR systems or components span multiple levels.
- Third, each domain must retain the authority and responsibility to enact and enforce data validation, certification, and security.
- Fourth, each domain establishes and enforces protocols, procedures, conversions, and metadata validation at the access points between the separate autonomous systems supporting each domain. Data packet management at the access points enables autonomous systems security and supports network stability.
- Fifth, active interfaces at the boundary between the two domains implement differential data distribution to C4ISR nodes and/or M&S federates.

These factors must be considered as we look to the current and future challenges in C4ISR and simulation interoperability.

2.1 Previous U.S. Approaches to Interfacing C4ISR Systems and Simulations

2.1.1 With Staff Level C4ISR Systems

One of earliest experiments in C4ISR to simulation interoperability – via standard message formats – was to link the Tactical Simulation (TACSIM) to the U.S. Automated Defense Information Network (AUTODIN) message system in support of the Tactical Exploitation of National Capabilities (TENCAP)

LEVEL (Environment)			Interoperability Attributes: Procedures	Applications	Infrastructure	Data
Enterprise Level (Universal)	4	c	Multi-National Enterprises	Interactive (cross applications)	Multi-Dimensional Topologies	Cross-Enterprise Models
		b	Federal Enterprise			
		a	DoD Enterprise	Full Object Cut & Paste		Enterprise Model
Domain Level (Integrated)	3	c	Domain Service/Agency Doctrine, Procedures, Training, etc.	Shared Data (Situation Displays Direct DB Exchanges)	WAN	DBMS
		b		Group Collaboration (White Boards, VTC)		Domain Models
		a		Full Text Cut and Paste		
Functional Level (Distributed)	2	c	Common Operating Environment (DII-COE Level 5) Compliance	Web Browser	LAN	Program Models and Advanced Data Formats
		b		Basic Operations (Documents, Maps, Briefings, Pictures Spreadsheets, Data)		
		a	Program Standard Procedures, Training, etc.	Advanced Messaging (Parsers, E-Mail+)	Network	
Connected Level (Peer-to-Peer)	1	d	Standards Compliant (JTA, IEEE)	Basic Messaging (Plain Text, E-mail w/o attachments)	Two Way	Basic Data Formats
		c		Data File Transfer		
		b	Security Profile	Simple Interaction Text Chatter, Voice, Fax, Remote Access, Telemetry)		
		a			One Way	
Isolated Level (Manual)	0	d	Media Exchange Procedures	N/A	Removable Media	Media Formats
		c	Manual Access Controls — NATO Level 3		Manual Re-entry	Private Data
		b	NATO Level 2			
		a	NATO Level 1			
		o	No Known Interoperability			

Figure 1. Levels of Information Systems Interoperability (LISI) Model

program in 1980. TACSIM generated Tactical Reports (TACREPs), Tactical Electronic Intelligence (TACELINT), and a variety of other messages in U.S. Message Text Format (USMTF) in both JANAP 128 and DOI 103 formats, providing unclassified, classified (collateral), and classified (SCI) text message traffic into the AUTODIN system.

During an Ulchi Focus Lens exercise in Korea in 1990, this capability led to a direct linkage – via message translation – from TACSIM to the Korea Combat Support System (KCSS) and the Korea Air Intelligence System (KAIS) for key

intelligence message traffic. KCSS and KAIS were the primary C4ISR systems which supported the Air Component Command (ACC) of the Korean Combined Forces Command (CFC). During this same event, there was a linkage developed and implemented between the Air Warfare Simulation (AWSIM) and Tactical Receive Equipment (TRE)/Tactical Related Applications (TRAP) systems. From TRAP, the information was fed through a TENCAP project component known as the Air Defense Systems Integrator (ADSI). This allowed enemy aircraft tracking data to be input to the air defense cell at the Control and Report Center (CRC). In this way, there was established a direct linkage of simulation data to major operations and intelligence centers, including the intelligence I&W centers, Electronic Combat Center, Control and Report Center, and Combat Operations.

Through the mid-1990's, these techniques were continued and expanded with the implementation of a Tactical Information Broadcast Service (TIBS) data link from the AWSIM, along with a somewhat realistic representation of threat emitters and the transmittal of that information to Constant Source (CS), Prototype Analyst Workstation (PAWS), Electronic Processing and Dissemination System (EPDS), Enhanced Tactical User Terminal (ETUT), and Tactical High Mobility Terminal (THMT). Many of these were developed by the Joint Electronic Warfare Center (JEWC), in support of platforms such as Rivet Joint, Senior Ruby, and Guard Rail. Each of these efforts early allowed additional simulation data to be fed directly to a variety of operational environments. But in each case, the interface was one-way-only, from the simulation to the C4ISR environment.

In 1994, the Warrior Preparation Center built a two way interface between AWSIM to the Contingency Theater Automated Planning System (CTAPS). The objective of the effort, known as Project Real Warrior (PRW), was to maintain the existing simulation to C4ISR interfaces, expanded those where possible, and to establish a database link from the CTAPS to AWSIM. The primary motivation behind this effort was the reduction of manpower within the exercise response cells by providing an automated entry of the Air Tasking Order (ATO) into AWSIM. Since the ATO can contain upwards of 2000 missions per day, this offered a significant reduction in manpower requirements.

In parallel with this effort, the United States Air Force (USAF) Battlestaff Training School (BTS), known as "Blue Flag," had another program, a CTAPS to Wargame Interface Controller (CWIC) working, which had similar objectives to PRW, but with the added objective of providing automated synchronization of databases between CTAPS and AWSIM. This allowed unit order of battle information to flow directly from CTAPS to AWSIM, simplifying the process, reducing time required for database builds, and ensuring consistency between the two databases.

While these projects were occurring, in January 1994 preparations were on going for an exercise in Japan, called Keen Edge. This was being supported by the Joint Warfighting Center (JWFC), using the Joint Theater Level Simulation (JTLS). During an extremely shortened development cycle (less than two months), a two way interface – using message parsing augmented by database mapping – was established between JTLS and CTAPS. This allowed an ATO, received from CTAPS, to be translated into flight orders and routes for JTLS, and entered into the simulation. In turn, simulation generated Tactical Data Link (TADIL) formatted messages could be provided to operational personnel. In addition, enemy Electronic Intelligence (ELINT) data was formatted and broadcast via operational links to the entire TRAP network.

At about the same time, in support of the U.S. Army Text and Experimentation Command (TEXCOM), the Army Experimentation Station (AES) was developing a suite of interfaces, called the Simulation Support Modules (SSM), between a variety of C4ISR systems, the Corps Battle Simulation (CBS), and the Combat Service Support Training Simulation System (CSSTSS). The C4ISR systems stimulated included, the All Source Analysis System (ASAS), the Maneuver Control System (MCS), the Advanced Field Artillery Tactical Data System (AFATDS), the Forward Area Air

Defense Command, Control, and Intelligence (FAADC2I) system, and the Combat Service Support Control System (CSSCS). This suite of interfaces – via message parsing augmented by database mapping – provided a two-way feed with AFATDS (e.g., Calls for Fire) and a one way feed with the other four systems. The information provided from the simulation included status information, as well as a variety of Command and Control (C2) actions.

These three early efforts in many ways influenced the development of the Modular Reconfigurable C4ISR Interface (MRCI) [19 & 31], which attempted to develop a standardized data output stream from a simulation to C4ISR systems and to incorporate a standardized method for converting C4ISR system inputs to the simulations. This effort was initially supported by DMSO and later by the Defense Advanced Research Project Agency (DARPA). MRCI was demonstrated during the Synthetic Theater of War (STOW) 98 experiment. While many aspects of the MRCI experiment were similar to earlier efforts in C4ISR to simulation interoperability, there were two unique features.

One unique MRCI feature was the attempt to develop a standard interface to the C4ISR environment, in contrast to previous efforts, which in general created unique interfaces to each C4ISR system. The other unique aspect was the attempt to develop and mature a technology for translating command and control directives (or commands) into simulation "orders." For this a tool known as the Command and Control to Simulation Interface Language (CCSIL) was developed.

Concurrently, with MRCI the Air Force and Army moved forward with a direct data download interface between AWSIM and CTAPS. Additionally, this two way interface sent orders and commands to AWSIM while passing the status of the combat entities back to CTAPS in the correct format, with doctrinally correct content and timing.

In 1997 the Army began an effort to replace the SSMs. Called the Run Time Manager (RTM), it extended the SSM's message parsing and database augmentation by capturing information via Distributed Interactive Simulation (DIS) Protocol Data Units (PDUs) and translating embedded CCSIL-like data.

2.1.2 With Entity Level C4ISR Systems

While most of the discussion, to this point, on the history of C4ISR to simulation interoperability has dealt with staff level C4ISR systems, there have been a number of efforts to develop these interfaces at the entity, and even the engineering level.

One of the early efforts in this arena was the development of a Live-to-Virtual Interface Device (LIVID) for use in the Army's 1995 Focused Dispatch Advanced Warfighter Experiment (AWE). Focused Dispatch's LIVID provided a voice and data interface between a Single Channel Ground and Airborne Radio System (SINCGARS) radio and a CECOM/MITRE SINCGARS Radio Model (SRM). The LIVIDs, SRMs, and SINCGARS radio base stations were used together to link the virtual and live domains. Both the real SINCGARS in the live environment and the SRMs in the virtual environment were connected to real C2 devises hosted on laptop computers. The SRM-LIVID linkage between the C2 devices and the simulation environment included a C2-system-specific interface, a core communications model, and a simulation-network interface.

This effort ran in parallel to, and was succeeded by, the Tactical Internet Model (TIM) suite of simulation software. The TIM suite roots are in the SRM, initially developed in support of Focused Dispatch AWE. Later versions of TIM were implemented to support not only training, but also analysis and testing. The TIM suite provided a realistic communications environment for training using Applique' (the predecessor to the Force XXI Battle Command Brigade and Below (FBCB2) system), prior to the Task Force XXI AWE. Follow-on efforts have incorporated FBCB2, as well as Global Positioning System (GPS) devices and HLA/Distributed Interactive Simulation (DIS) protocol-compliant simulations.

During this same timeframe, at the USAF BTS, an interface was developed from AWSIM-Scenario Toolkit and Generation Environment (STAGE). This interface provided direct stimulation to air defense radars. AWSIM-STAGE was used during Roving Sands 1997 (a large joint training exercise which brought together constructive, virtual, and live simulations).

In the fall of 1994, the Chief of Staff of the Army (CSA) tasked the commander of Space and Missile Defense Command (SMDC) to build a Tactical Operations Center (TOC) that would integrate the four pillars of Theater Missile Defense (TMD) by providing a single focus to manage the "sensor to shooter" activities required to address time critical targets. The primary tool developed by this effort was the Tactical Simulation Interface Unit (TSIU). The TSIU reads simulation (sensor based) signal/transmitter PDUs from a DIS based simulation network and translates this information into the appropriate command and control workstation. The TSIU does not directly read entity or aggregate PDU information, nor does it provide truth data to the command and control workstations. A sensor must identify and report (for enemy forces) or a command and control entity must report (for friendly forces) via the signal/transmit PDU in order for tactical messages to be forwarded to the C2 workstation.

The TSIU was initially demonstrated in the 1994 Atlantic Resolve exercise. Since that time it has participated in exercises ranging from battalion through CINC level. TSIU has been used to stimulate all five of the Army's ATCCS systems, as well as FBCB2.

In April 2000, Janus (an Army constructive simulation) was interfaced – via the Simulation Testing Operations Rehearsal Model (STORM) – with both the Army's five ATCCS systems and FBCB2 to support the second FBCB2 Limited User Test (LUT). STORM was developed by the Army Operational Test and Evaluation Command (ATEC); during the LUT, it stimulated two live Brigade Combat Team (BCT) TOCs, two live Task Force TOCs, two live task forces, and a live opposing force (OPFOR) armor battalion. STORM was used to simulate two additional Task Forces and associated BCT slice elements, to ensure realistic Tactical Internet (TI) communications loading. It also wrapped simulated OPFOR units around the live OPFOR battalion in order to provide a realistic threat environment. As described in McConnell et al [33], STORM generated Situation Awareness (SA), C2, and intelligence Joint Variable Message Format (JVMF) messages – via the JVMF Library (version 15.6) – for the simulated forces and transmitted them to the live forces over the TI. The simulated forces appeared on the live force FBCB2 screens, and the live force appeared on the STORM screens. FBCB2-equipped live forces were not able to differentiate the live forces from the STORM simulated forces.

2.2 Previous and Ongoing International Efforts to Couple M&S and C4ISR Systems

This subsection gives a rough overview on what's going on in the international community in the area of coupling (or interfacing) C4ISR systems and simulations. The North Atlantic Treaty Organization (NATO) M&S Master Plan [35] defines at least two application domains for which C4ISR systems and simulation systems have to be coupled:

- For Computer Assisted Exercises (CAX) it is essential that the warfighter can be trained as he is supposed to fight (i.e., that his "go to war" Combat Information System (CIS) should reflect present information about simulated reality in the same way it would in a real operation). Thus, the simulation system generating the information and executing the orders the training audience gives to their simulated units has to be coupled with the CIS.
- For Operation Research Support to Operations (i.e., online alternative course of action analysis, optimization problems, what-if analyses, etc.), the integration of respective applications into the C4ISR systems is necessary. Simulation systems are a potential candidate for this functionality [53 & 54].

2.2.1 NATO Efforts

Supreme Headquarters Allied Powers Europe (SHAPE) is planning to develop a CAX Center for training on joint operations at its level of command. Within the CAX Center, the CIS of SHAPE will be integrated, in part to insure realistic training of commanders and their forces.

Supreme Allied Commander Atlantic (SACLANT) realizes the coupling of its Maritime Command and Control Information System (MCCIS) with maritime simulation systems using the Gold message format to share necessary information. Again, the application domain is CAX.

NC3A is working mainly with JTLS and is also focusing on CAX. Under Project XC (CAX) at NC3A, the team has coupled several CIS and simulations for exercise purposes using different technical approaches.

2.2.2 National Level Efforts

France uses its Stradivarius simulation system for CAX applications as well as for after action analysis and simulation based acquisition. One of the purposes for developing this simulation system was to test the functionality and efficiency of the air defense system, including radar's, weapon systems, and command and control. Thus, the interface to these air defense systems has been an integral part of Stradivarius from its inception. Stradivarius supports AdatP3 messages and Datalink (Surveillance and Control): Link 1, Link 11, Link 14, Link 16 and specific radar links.

Germany promotes the federation approach for the coupling of C4ISR systems. It is one of the leading nations concerning data management having already established a respective federal agency for data management (Daten-managementorganisation der Bundeswehr, DMO Bw).

- The same integration method used for C4ISR systems is also being used for decision support simulation systems.
- For CAX purposes, alternative means of stimulating C4ISR systems are being evaluated. The use of standard message interfaces is one candidate and the use of special domain areas within the databases (i.e., the definition of a "simulation system user" within the C4ISR system) is also being proposed.
- For the simulation systems, the German Proposed Standard Interface for Simulation, introduced by [34], is planned to become the standard interface for linking M&S-to-C4ISR.

Italy is working on a federation solution using ATCCIS as a common shared data model. In some areas, they are working closely together with Spain. However, their work focuses exclusively on the integration of C4ISR systems. The use of simulations – to stimulate Italian C4ISR systems – is only at the edge of the scope.

Netherlands coupled its KIBOWI system (Kiviet and Borawltz; the two developers) with several national CIS. KIBOWI is similar to CAX system with a decision support system for online analyses. The coupling is done by data replication of respective data domains between the two systems.

Portugal has no problem in coupling its CAX system Visualização Gráfica do Terreno em Modelo Digital 3D (VIGRESTE) with Allied Tactical Command and Control Information System (ATCCIS) compliant C4ISR system. The VIGIRESTE model developers chose ATCCIS as the basis for the object model being used within their simulation model. Thus, a real fusion approach is working that have been planned from the beginning. This was possible since Portugal started from scratch in both the C4ISR and CAX worlds with a harmonized approach.

Sweden participates in the Partnership-for-Peace (PfP) training efforts as a leading nation, using TYR, a simulator to operate a game at command level. Sweden has begun development of next generation where HLA will be the architecture of the system. Sweden has also started investigating how HLA can be a part of the Swedish Armed Forces C4ISR architecture and how to apply a model based way of thinking in C4ISR-systems. ATCCIS is being considered in connection with this work. Sweden is one of thirteen members in the Western Europe Armament Group (WEAG) EUCLID program Common European Priority Areas (CEPA)

11:13 titled "Realising the Potential of Networked Simulation in Europe."

The United Kingdom gained experience early on during the FlasHLAmp experiments. Where C4ISR systems were coupled with various combat simulations.

Many efforts are ongoing within the International community. However, these efforts are largely uncoordinated. As a starting point, lessons learned should be shared among nations through the SIW C4I and International Forum.

2.3 The NATO and DoD Modeling and Simulation Master Plans

In late 1994 and early 1995, the Defense Modeling and Simulation Office (DMSO) conducted a baseline assessment of all DoD M&S. From this assessment, DMSO identified six DoD-wide M&S objectives that were, in October 1995, published in DoD's first M&S Master Plan; *DoD 5000.59-P, Modeling and Simulation Master Plan* (MSMP) [10].

For each objective, DoD 5000.59-P identifies key issues and actions [10]. Because no single model or simulation can meet all of the needs of the M&S community, the objectives do not identify any specific solution. Rather, each objective identifies those aspects that:

- Are common across all M&S (both military and non-military);
- Foster credibility and re-use [or cost avoidance]; and,
- Where appropriate, ensure interoperability.

DoD 5000.59-P establishes the HLA and Conceptual Modeling of the Mission Space (CMMS) as, respectively, the first and second components of the DoD M&S Technical Framework [10 & 12].

Taking the DoD MSMP as one input, in November 1996, NATO began to develop a NATO MSMP. The Conference of National Armaments Directors (CNAD) established a Steering Group on NATO Simulation Policy and Applications with a mandate to craft an Alliance approach to simulation in order to improve Alliance operations. The resulting efforts resulted in the NATO Document AC/323 (SGMS) D/2 [35]. It establishes a co-operative approach for applying advanced simulation techniques to aid in satisfying the needs of the NATO Alliance and its member nations. It is assumed that successful execution of the master plan will promote the aim of Alliance-wide simulation interoperability and reuse, while also providing national and NATO bodies with significant modeling and simulation interest, with the necessary latitude to meet their specific needs.

The NATO MSMP identifies four areas where M&S can provide a "value added:"

- Defense Planning,
- Training,
- Exercises, and
- Support Operations.

The objective to couple C4ISR systems and respective simulation systems is an explicit topic for the training, exercises, and support operations domains.

2.3.1 HLA

Objective 1 of the DoD M&S Master Plan states, "Provide a common technical framework for M&S." Sub-objective 1-1 includes the establishment of a common, high level simulation architecture to facilitate interoperability of all types of simulations among themselves and with C4ISR systems, as well as facilitate the reuse of M&S components. To meet this objective the Under Secretary of Defense for Acquisition and Technology (USD A&T) designated the HLA as the standard technical architecture for all DoD simulations [26].

Future DoD C4ISR interface developers must develop interfaces that take into account not only the HLA, but also the DII COE and JTA mandated message formats, data models, and data exchange standards.

2.3.2 Conceptual Models of the Mission Space (CMMS)

CMMS provides simulation-independent, warfighter-based descriptions of the real world.

CMMS does this by linking Subject Matter Experts (SMEs) with simulation developers and users via:

- Actual subject matter descriptions in the form of knowledge acquisition products;
- A common repository for use and re-use; and
- A technical framework for integration and interoperability of the knowledge acquisition products registered in the common repository [13].

Known as Mission Space Models (MSMs), these subject matter descriptions are the primary components of DMSO's CMMS program [23]. Intended to describe how a specific task or action is conducted, MSMs – via a hierarchical form where each subordinate level, sub-process, or function provides greater detail – are the first abstraction of real world processes [13 & 23].

With regard to M&S-to-C4I interoperability, MSMs – if used – have the potential to make personnel attempting to link M&S and C4ISR systems realize that passing messages, whether in the form of interactions or objects, between simulations and C4ISR systems is comparatively straight forward. Far more difficult interoperability problems are in the areas of database synchronization, data cohesion, and data collection (e.g., After Action Reviews).

2.4 JTA

The DoD JTA [26] has three mutually supporting objectives. The first is to provide the foundation for interoperability and seamless flow among all tactical, strategic, and sustaining base systems that produce, use or exchange information electronically. The second objective is to provide guidelines and standards for system development and acquisition that will dramatically reduce cost, development time, and fielding time for improved systems. The third objective is to influence the direction of the information industry's technology development and research and development investment so that it can be more readily leveraged in DoD systems.

To better understand the role of M&S in supporting these objectives, we note that M&S is used, as shown in Figure 2, to support the analysis and development of the real world Operational Architecture (OA) and System Architecture (SA) views. For example, for the OA view, information models are built (often using IDEF0/IDEF1X) to represent real-world systems and the interfaces and the data flow between them. These models are of three basic

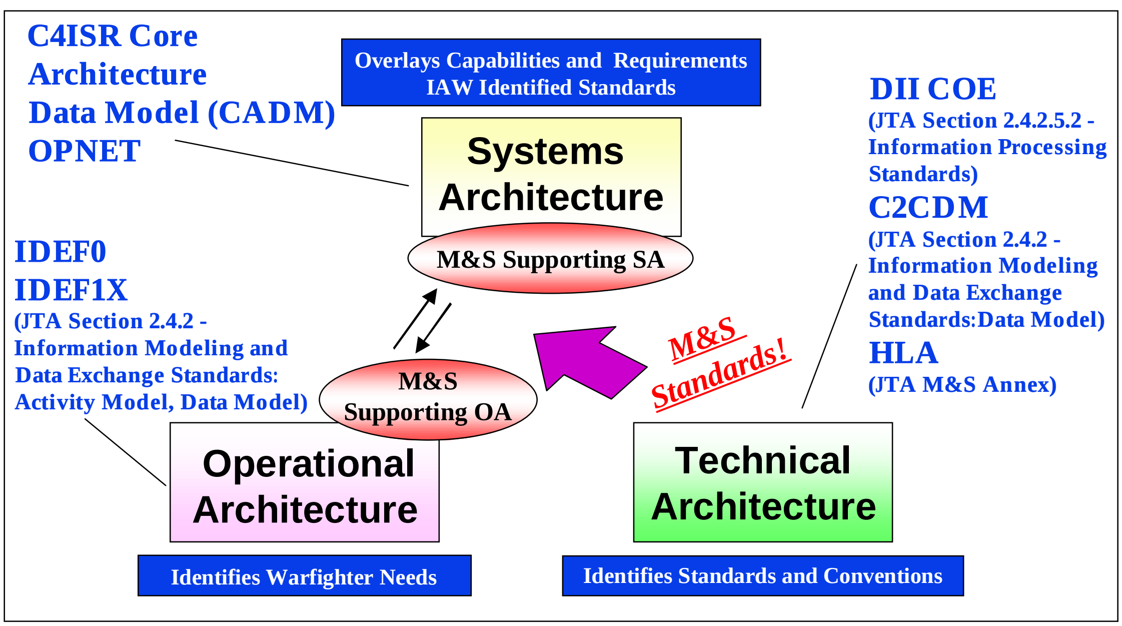

Figure 2. M&S Role in Support of the Operational, Systems, and Technical Architecture Views

types: activity, data, and interface models. Activity models are representations of the mission area applications or activities that an organization must perform to achieve its mission. They document processes and data flows, can be validated against the requirements and doctrine, and approved by the operational sponsor. As such, they help define both what to build and the information flows necessary to support command and control of these units, based on requirements. The data models are used as a logical basis for physical data exchange and shared data structures including message formats and schema for shared databases. Interface models represent connection solutions at the infrastructure level between the COE and HLA-compliant RTIs. For the SA view, M&S is used to develop the "wiring" diagram that shows how the various elements communicate with one another, thus providing the communications design for the units and processes that the OA view specifies. However, it is unclear how the JTA applies to such uses of M&S.

The JTA provides a set of standards, some of which are particularly relevant to M&S in the areas of data models and software architectures. For the C4ISR domain, these are specified in the JTA as the C4ISR common data models and the DII COE architecture. The DII COE consists of common reusable software components. Within the JTA, M&S is a separate domain with its own annex. In that annex the HLA is specified as the set of relevant standards and the software architecture for M&S. However, the M&S annex is not clear on the relationship between the C4ISR domain and the M&S domain. This has led to confusion on which set of standards apply to simulations, C4ISR systems, and C4ISR Interfaces.

2.5 DII COE

In JTA version 2.0 [26] DoD adopted the Defense Information Infrastructure Common Operating Environment (DII COE) concept and mandated the DII COE baseline specification and the DII COE integration and runtime specification. The DII COE is mission application independent, as well as:

- An architecture;
- An approach;
- A collection of reusable software;
- A software infrastructure; and
- A set of guidelines and standards.

Per the DII COE Architecture Oversight Charter [9], portions of the DII COE are being updated using requirements generated by 20 joint service Technical Working Groups (TWGs). The Army is the lead for several TWGs that are critical to M&S C4ISR interface developers, such as: the COE Message Processor (CMP), Communications Services, Data Access Services, and Alerts. There are also TWGs for the Common Operational Picture; Visualization and 3D; and Mapping, Charting, Geodesy, and Imagery via the Joint Mapping Toolkit (JMTK). Just recently, the DII COE Executive Oversight Group established a new TWG – M&S – chaired by DMSO.

2.6 Information Assurance/Security

Information Assurance (IA) encompass all actions that "protect and defend information and information systems by ensuring their availability, integrity, authentication, confidentiality, and non-repudiation. This includes providing for restoration of information systems by incorporating protection, detection, and reaction capabilities" [25]. Security demands an ability to tailor access to system components in concert with policy to enable forces to meet mission and/or training requirements. Past efforts to link M&S and C4ISR domains have largely ignored IA/security issues. The general focus has been on enabling connections; not on establishing access security or providing tools to ensure information integrity [2].

As more systems are linked, as applications are extended, and as more users are added, the importance of information assurance grows. In the future, IA must be a major consideration in designing links between and within M&S and C4ISR domains. Training objectives and political goals will increase the need to link federations with multi-national forces while each force uses its native simulations and C4ISR systems. This drive to extend the training audience will not offset the need to "train as you fight." Hence, multi-domain frameworks will demand improved IA designs with security

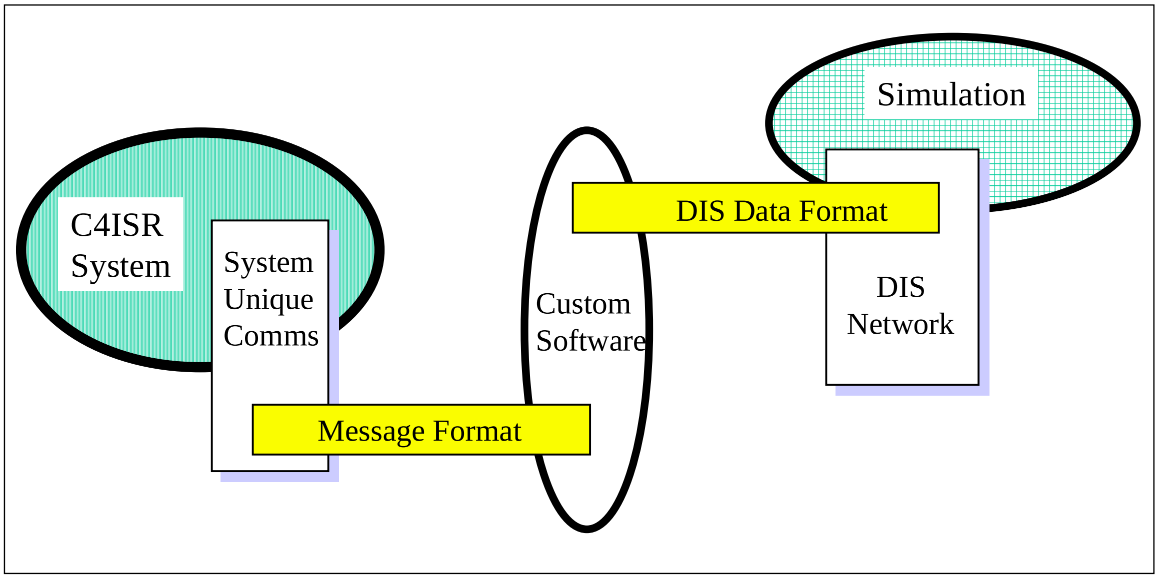

Figure 3. Legacy C4I to M&S Interface Standards

features that permit authorized access while enhancing protection.

Implementation of data filters within a domain has significant performance implications [16]. Hence, designs should include special security features at the intersecting boundary layers between domains. Thus, users and applications within one domain may be correctly restrained from access or interference within another. Hence, totally seamless links between domains is not desirable. Rather, interfaces must strive to provide facile, automated, consistent access across these domain boundaries to authorized users and authorized programs.

Within the C4ISR domain, systems are based on a variety of protocols. These differences impose barriers to interoperability within this single domain. Addition of M&S components to this equation will not resolve this C4ISR interoperability issue. However, the DoD community has taken strides to provide both near and long term solutions. The Office of the Secretary of Defense (OSD) and DISA have worked to develop an interoperability model, LISI, discussed in detail in Section 4.3. Moreover, near term projects have implemented viable interfaces between disparate systems as demonstrated by the Rosetta program in the Link-16/Variable Message Format (VMF) Conversion Advanced Concept Technology Demonstration [57]. However, this gateway fails to include critical security features or record and monitor critical metadata. Thus in the near term, reusable links between the HLA RTI and target elements of the C4ISR domain could leverage common gateways when these extended with security features and metadata support. In the long term, other options may be developed.

2.7 Relationship between C4ISR and Simulation Domains

Figure 3 shows a generalization of how most DIS M&S-to-C4I interfaces are currently implemented. Because the DIS standard does not align well with current tactical message formats, there must be a software translator to perform the interface functions. Only a limited amount of information passes over the interface, and there are many design options, so that each interface project will usually develop new software. Projects have also interfaced C4ISR equipment to the HLA, such as the Modular Reconfigurable C4I Interface [19 & 31]. Such projects have emphasized the need to minimize translation and it's overhead through use of common data elements [31 & 49].

At least one missing piece is a data interchange format that assists in the data alignment of C4ISR systems with simulations. A good example of this is SEDRIS (http://www.sedris.org). The Synthetic Environment Data

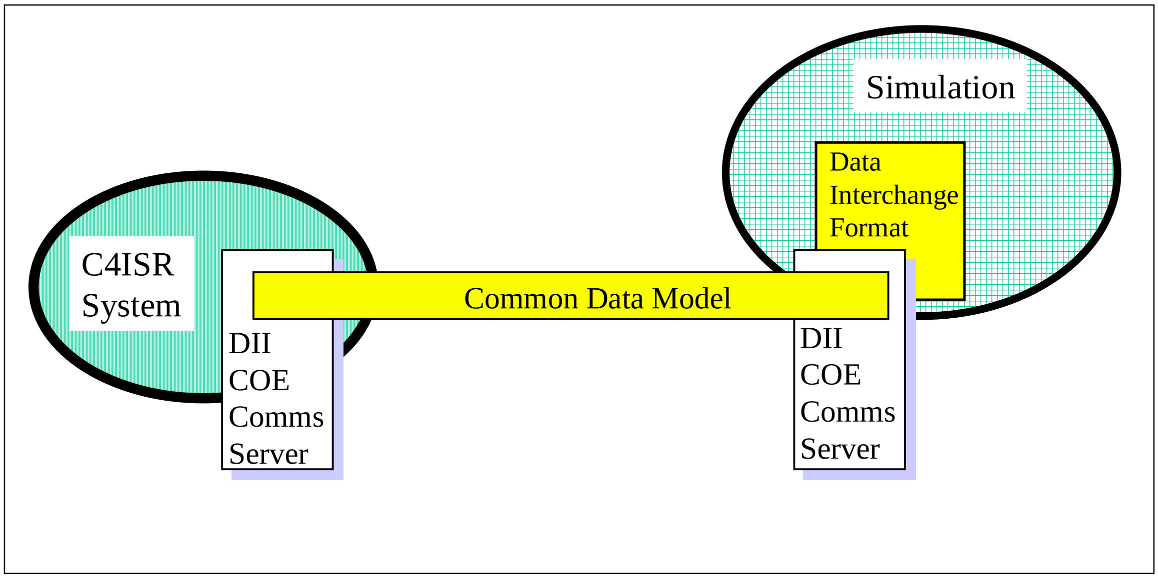

Figure 4. A C4I Developer's View of C4I to M&S Interface Standards

Representation and Interchange Specification (SEDRIS) could be a Data Interchange Format (DIF) between the simulation terrain formats (such as S1000 or Standard Interchange Format (SIF)) and the C4ISR terrain formats (Digital Terrain Elevation Data (DTED) or Vector Product Format (VPF)). Neither the simulations nor the C4ISR systems use the SEDRIS format, but it allows conversion of data by providing a unifying representation.

There is a large difference in viewpoint between the developers of Simulations and the developers of C4ISR systems, regarding applicable standards. C4ISR developers feel strongly that simulations should use the data elements that real systems use. This could lead to a standards framework, as shown in Figure 4, with a DII COE segment in the simulation for direct database-to-database data element transfer.

Figure 5 shows a standards based interoperability solution that is simulation oriented. It assumes that the HLA will be hosted on C4ISR platforms, possibly as a DII COE segment. But, the SG's research indicates that C4ISR developers are not familiar with the HLA and have traditionally not accepted this as a valid requirement for their system.

Figures 4 and 5 also show that making a DIF – or an Application Programmer's Interface (API) – a standard does not constrain the architecture. There will still be a need for a DIF even if one architecture predominates. Until both architectures have been designed with, and use the *same underlying data elements* there will be a need for translation. However, a good standard will minimize translations.

A framework must still be developed for aligning JTA M&S and C4ISR standards.

2.8 DoD Policy Concerning C4ISR and Simulation Interoperability

The labyrinth of interoperability policy can present many obstacles to unwary, unsuspecting C4ISR or M&S program managers, system developers, and users. Sutton [48] conducted an analysis of military interoperability policy to provide a roadmap of this complex, confusing, and often frustrating maze of policies.

2.8.1 C4ISR Interoperability Policy Elements

The following types of interoperability policy elements were found in C4ISR interopera-bility

policy documents, but not in M&S policy documents:

- Certification and Re-certification
- Compatibility
- Doctrine
- Integration
- Interface Standards
- Interoperability Problem Reporting
- Interoperability Requirements
- Interoperability Testing, Operational Testing and Evaluation, Testing and Evaluation
- Mapping, Charting, Geodesy Data Standards and Specifications
- Mission Need Statement (MNS) and Operational Requirements Document (ORD)
- Interoperability Waivers

2.8.2 M&S Interoperability Policy Elements

The following types of interoperability policy elements were found in M&S interoperability policy documents, but not in C4ISR policy documents

- Accreditation
- Common Databases and Tools
- Data Interchange Standards and Protocols Establishment
- Data Verification, Validation, and Certification
- Federations
- HLA
- Internet Standard and Protocol Establishment
- No-Pay/No-Play Deadlines for HLA Conformance
- Object Model Data Dictionary (OMDD)
- Object Model Template Data Interchange Format (OMTDIF)
- Risk Management (Secretary of the Navy Instruction (SECNAVINST) 5200.38 only)
- Standard Simulator Data Base

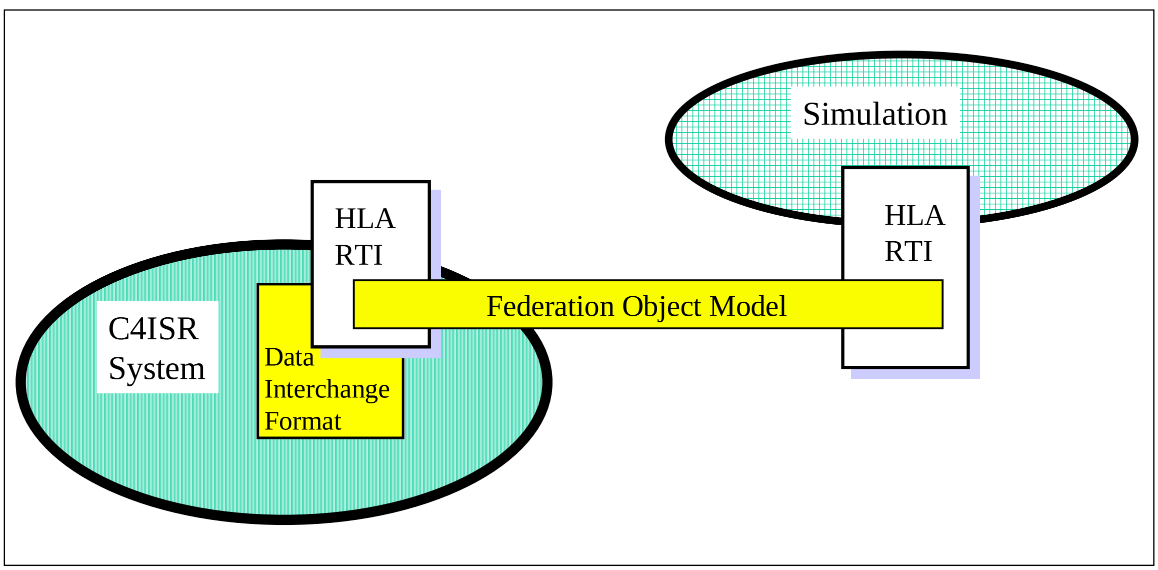

Figure 5. A Simulation Developer's View of C4I to M&S Interface Standards

Interchange Format (SIF)
- Synthetic Environment Data Representation Interchange Specification (SEDRIS)

2.8.3 Interoperability Elements in both C4ISR and M&S Policy Documents

The following types of interoperability policy elements were found in both C4ISR and M&S interoperability policy documents:

- Data Interchange Standards for Applications Sharing
- DII COE
- Human-Computer Interface Standards
- Information Modeling, Processing, Systems Security, and Transfer Standards
- Internet 5-Layer Network Model
- Internet Standards and Protocols
- Interoperable with Joint and Combined C4ISR Systems and Operations
- JTA
- Open Systems Architecture Standards and Protocols
- Seamless, Transparent Open Systems Infrastructure
- Standard Data Elements Exchanged by C4ISR Systems and M&S Applications
- System Design and Integration Rules for Technical Architecture

2.8.4 Interoperability Elements not in Either C4ISR or M&S Policy Documents

The following types of interoperability policy elements were found to be missing from interoperability policy directives in both domains:

- Technology Integration
- Simulation Based Acquisition (SBA)
- Formal Interoperability Theory and Modeling
- Interoperability Performance measurement and standards

2.8.5 Interoperability Policy Consistency

Quantified interoperability performance measures and metrics are not available in either the C4ISR or M&S domains. It is, therefore, impossible to measure and compare interoperability performance in either domain; and the effects of changes to interoperability policy can never be known or understood. C4ISR inter-operability policy defines detailed, explicit processes and procedures for achieving C4ISR system interoperability, but M&S policy generally does not.

3. C4ISR-to-Simulation FOMs

This section includes a general discussion of C4ISR FOMs under development, and their impact on M&S-to-C4I interoperability. (A copy of each FOM is available for download at http://www.sisostds.org/doclib/cat_display.cfm?id_number=48.)

3.1 A Prototype C4I FOM

The Prototype C4I FOM is the result of a U.S. Army requirement to develop a common environment to facilitate the use of constructive, virtual, and live simulations in the evaluation of C4I systems in the Research, Development, and Acquisition (RDA), the Advanced Concepts and Requirements (ACR), and the Training, Exercises, and Military Operations (TEMO) domains. To be effective, the simulation environment must be capable of interoperating with real C4I systems in a manner that is flexible, extensible, and promotes re-use of software components. The prototype C4I FOM is a step toward providing this capability by providing a standardized representation for interoperability that can be applied to a variety of C4I systems.

The feasibility of the FOM to support this kind of objective simulation environment is currently being demonstrated through an effort to transition the TIM to the HLA. A subset of the prototype C4I FOM, plus additional domain-specific classes and attributes, has been used as the instantiation of the FOM for the TIM environment. The TIM environment provides a realistic interface to the virtual world for the Army's battalion and below C2 system, FBCB2.

In developing the initial version of the prototype C4I FOM, object-oriented techniques were used to gather requirements, synthesize the results, and map this information into a HLA FOM representation. An Object-Oriented Analysis (OOA) and an Object-Oriented Design (OOD)

methodology was used to generate successive layers of increasing detail, allowing for the capture of many of the details of the problem domain. The information was specified in a manner prescribed by the HLA Object Model Template (OMT). Through this process certain key areas were identified including C4I Systems, Communications Device, Communications Network, Communications Effects, and Messages. Initially the FOM was focused on Army lower echelon (battalion and below) exchange of Situation Awareness (SA) and battle command messages through their C2 systems. Included in the FOM were the specification of the various categories of communications equipment used (radios, routers, controllers), configuration of the networks (platoon, company, and battalion level networks), and the effects on data transmission resulting from the combination of environmental factors, network latency and traffic loading, and characteristics of the radio. As work on this effort continues during Fiscal-Year 2000 (FY00), the scope of the FOM will evolve to include to some extent higher echelons (i.e., brigade and division), Information Operations (IO), intelligence, and sensors. The current version of the prototype C4I FOM is available for viewing at the following SISO C4I Study Groups Document Library: http://www.sisostds.org/doclib/ index.cfm.

3.2 TSIU FOM

The SMDC, Exercises and Training Division, is developing an HLA compliant version of the TSIU. The TSIU provides a data interface between the virtual simulation environment and the Army Battle Command System (ABCS).

The concept of the TSIU is to translate the simulation update data into the appropriate tactical format for transmission to tactical C4ISR systems. Historically the TSIU has received the simulation data via a predefined set of message updates utilizing a DIS Transmitter/Signal PDU implementation. The information from the simulation network is translated and formatted by the TSIU and then transmitted on a separate tactical network to linked C4ISR systems. The TSIU provides all message formatting capability, therefore eliminating the requirement for participating simulations to maintain the ever-evolving tactical message format specifications. Following the modeling and simulation community's migration to the HLA, the TSIU program has recently implemented a prototype C4ISR FOM to achieve a working HLA interface to the simulation environment.

Building on previous simulation integration experience, the TSIU C4ISR FOM incorporates many of the data elements defined by the original simulation message set. The simulation updates, modeled exclusively as non-persistent HLA interactions, are defined by category and support a variety of tactical message classifications including Maneuver, Intelligence, Air Defense, Fire Support, and Combat Service Support. The specific interaction parameters are defined to a level of detail that supports efficient object model expandability and general readability. In addition to the C4ISR FOM development, the TSIU has incorporated a FOM mapping capability, which will allow the TSIU to seamlessly integrate with other HLA FOMs, as future exercises require. Currently, the TSIU has successfully integrated with SMDC's Extended Air Defense Simulation (EADSIM) using the TSIU C4ISR FOM. Recent tests have included the TSIU receiving maneuver and intelligence interaction updates from EADSIM and using the interaction data to generate and transmit tactical messages to networked C4ISR systems.

3.3 J6 NETWARS FOM

Network Warfare Simulation (NETWARS) is a Joint Chief of Staff modeling and simulation initiative that has three objectives:

- Perform communication burden assessment for a Joint Task Force (JTF),
- Analyze operational communication plans, and
- Assess performance impact of new technology on JTF performance.

The underlying principle of NETWARS is the development of standard models that enhance interoperability and re-usability. The NETWARS modeling standard defines class structures from which a minimum set of essential attributes is defined. For example, the radio class has transmission rate, power, and

modulation as its minimum set of attributes. The standard would also provide a common naming convention to facilitate NETWARS interface with other models. Hence, a developer would use the minimum set of attributes and would parameterize these attributes appropriately when modeling a specific radio.

The NETWARS FOM is based on this class definition and essential set of attributes. Depending on the type of models that are to be federated with NETWARS, this FOM provides the necessary information to enhance the probability of success when it is required to federate with other modeling environments.

3.4 DII COE C4I FOM and the C4I Ambassador

The Naval Research Laboratory is developing a C4ISR FOM for DII COE based C4ISR systems under the sponsorship of DMSO and DISA.

The C4I Ambassador software provides two-way links between the embedded RTI and the DII COE Services, data bases and C4ISR Mission Applications. It interprets the FOM (parses and reformats data as necessary) and manages simulated data distribution within C4ISR. This development builds on the technology contained within the recently released Global Command and Control System (GCCS) Embedded Training Segments for inserting training data into operational GCCS systems.

3.4.1 Purpose

The (DII COE) C4I FOM and the C4I Ambassador are developed to embed the RTI and all necessary software within C4ISR systems to allow them to function as Federates within an HLA Federation. The resulting C4ISR Federates provide the following interoperability functionality:

- Facilitates two-way interactions between C4ISR systems and simulations.
- Allows multiple, simultaneous Federates on a single C4ISR LAN.
- Provides both database-to-database and message based transactions.
- Processes real-time, faster than real-time and slower than real-time simulated data.
- Ensures C4ISR mission applications relate the same way to simulated and real C4ISR data.
- Allows C4ISR Federates to reside and function within operational C4ISR without disrupting real world operations.

3.4.2 DII COE C4I FOM General Characteristics

The C4I FOM work originally began as the Simulation-C4I interface used in Synthetic Theater of War (STOW) 97 and 98 Exercises. It has progressed to be used for the Joint Theater Level System (JTLS) – GCCS Federation and the Naval Simulation System – GCCS/Maritime Federation. Work is underway to incorporate this technology into the Navy Modeling and Simulation Management Office's Embedded Simulation Infrastructure Program to move simulations into GCCS/Maritime and the COE. Subsets of the overall C4I FOM are based on standard military messages, database to database transactions and the Real Time Performance Reference FOM (RPR FOM).

Database-to-database transactions yield the highest level of interoperability potential. The FOM design approach for this subset is to define additional objects and transactions for each new federation in such a way that it is consistent with C4ISR data content and internal database organization. The objects defined to date are generally associated with military platforms and units. The C4I FOM is composed of objects that directly represent the Platform and Unit objects stored in the DII COE Tactical Database Manager (TDBM).

There are also interactions in the FOM that are used to send platform position change requests (indirect control) to the simulation. These interactions are modeled after routinely broadcast real world orders such as PIM Track, Screen Kilo and Four Whiskey Grid. In addition, DII COE Federates have object ownership capabilities and the C4I FOM defines the means for C4ISR to initialize scenarios, provide updates on real track behaviors, and control forces during exercises (for those

simulations capable of supporting) these interactions.

3.5 Simulation-Based C2 Integration Framework

A team of researchers at the U.S. Air Force Electronic Systems Center (ESC) recently completed a prototype featuring Airborne Warning and Control System (AWACS)-related software applications operating within a simulated battle. This effort represents a first step toward a Simulation-Based C2 Integration Framework (SBCIF) for testing C2 system interoperability as MITRE and ESC team to migrate existing Air Force systems to the Integrated C2 System (IC2S).

MITRE internal research in Simulation to C2 System Infrastructure is investigating technologies, tools, and interface approaches necessary to make the SBCIF vision a reality. With the trend in modern warfighting toward increased C2 system interoperability, system-specific test harnesses traditionally used to exercise stovepiped C2 systems will no longer suffice. Instead, a synthetic battlespace is needed that provides a more comprehensive, interactive battle environment within which C2 systems can refine information exchange mechanisms and processes.

The synthetic battlespace within the SBCIF will be composed of existing simulations connected via the HLA. C2 systems that have an HLA interface capability will be able to take advantage of the SBCIF to exercise data exchange capabilities within a realistic battle environment.

In the AWACS prototype, the battle is “fought” by a mission-level battle simulation. As the battle plays out in real time, information about airborne platforms is pumped over a High Level Architecture (HLA) Runtime Infrastructure (RTI) to a real-time CORBA-based AWACS infrastructure. There the data is parceled off to AWACS-related applications for processing and display.

The AWACS effort demonstrates the potential of the HLA as a mechanism for driving real-time C2 systems with simulated battle data for testing, experimentation, training, and other purposes. With this prototype AWACS becomes the first ESC system to achieve an HLA connection to the SBCIF. Fully realized, the SBCIF will offer a wide variety of C2 systems the opportunity to take advantage of an HLA-based synthetic battlespace to refine operational C2 capabilities.

3.6 Joint Theater Level Simulation (JTLS) - GCCS-NATO C2 Federation

The JTLS-GCCS-NATO C2 federation was developed to examine the use of the HLA to build interfaces between C2 systems and simulations. The federation comprises a set of multinational command and control systems (GCCS and the NATO Consultation, Command and Control Agency’s (NC3A) ICC Air Track display) and exercise support tools, stimulated by JTLS. The federation is a partnership of three organizations, the DISA, the U.S. Joint Forces Command Joint Warfighting Center (USJFCOM/JWFC), and NC3A. Each organization has a vested interest in finding affordable and extensible approaches to the task of linking combat simulations to fielded C2 systems to support training. DMSO joins the partnership to provide the HLA, the enabling technology that serves as the foundation for linking C2 systems to simulations.

3.6.1 Federates

The JTLS Combat Events Program (CEP) is the core process of JTLS. The CEP does all the modeling of the combat units, the events, and the battlefield environment. It contains the algorithms for computing the state of simulation objects, and reacts to orders created by human operators (players).

GDS, the G-Protocol Data Server (also called the Genis Data Server), is used as the data management and distribution component of the JTLS system. The CEP sends state information for all simulation objects to the GDS. The GDS, in turn, services the information needs of an array of simulation “clients,” including player consoles, data display terminals, and data translation modules that enable linkage to C4ISR systems.

The Global Command and Control System (GCCS) is the battlefield situation display and information management system for theater and joint task force level commanders and their staffs.

The NC3A Order Translation Modules (OTMs) are a response-cell support tool that enables role players to enter mission orders using more "natural" operational terms and graphics. The OTMs then transform this data into a set of orders for subordinate units that can be executed in JTLS. The three OTMs that are included in the federation represent land (LOTM), naval (NOTM), and air (OTMA) functionality.

The NC3A Aggregator is a response-cell tool intended to reduce the role players' workload by making it easier to discover and report status information for aggregate units (made up of several smaller sized units that are explicitly modeled in the JTLS game). The aggregator calculates the status information for an aggregate unit from the data for the individual constituent units.

The NC3A ICC Air Track Formatter is a software module that takes simulation state data for aircraft, air missions, airbases, SAM sites, and radar sites as input and generates output in the appropriate format for several NATO C4ISR devices, including OPUS, ACBA, and ICC.

The NC3A Bi-MNC Report Generator is a family of processes that translate a subset of JTLS simulation data into well-structured, formatted NATO messages. These messages can then be delivered to the training audience via real-world communications systems. The modules accomplish the end-to-end process of preparing and injecting the reports into the communications backbone.

3.6.2 1999 Federation Activities

During 1999, the federation team worked toward the goal of transitioning the federation to the JWFC and NC3A for use in computer-aided exercises. The JTLS team re-designed and re-implemented the RTI interface module to improve stability and performance during federation execution. The GCCS team experimented with the implementation of a two-way data flow, allowing naval orders to be sent from the GCCS workstation to the JTLS. The NC3A team added two new federates, the Air and Naval Order Translation Modules (OTMs), to improve usability of the federation during exercises. Finally, extensive testing during the year helped to improve the performance and reliability of the federation with large exercise-level scenarios.

3.6.3 2000 Federation Activities

Immediate objectives for the federation are to finalize the transition from the laboratory to operational exercises. In the spring of 2000, NC3A deployed the federation in the first of several NATO exercises. In addition, the JWFC is also examining potential applications of the federation later in 2000. Both events will warrant continued testing with an emphasis on improving reliability, performance, and developing a better understanding the potential uses of the federation in an exercise. Other HLA tools that would be new federates are under evaluation as aids for monitoring the federation and collecting data during execution.

3.7 Intelligence, Surveillance, and Reconnaissance (ISR) Analysis FOM

The ISR FOM was developed to support the linkage of legacy and newly developed federates into an analysis federation. This analysis federation is intended to support the various, regularly occurring DoD and Intelligence Community studies that have a need to be able to analyze the impact of intelligence community-derived information upon the battle in terms of quality, quantity, and timeliness of related products.

This ISR FOM breaks out the various aspects of the intelligence cycle, and subdivides each into its respective subordinate detailed processes. As such, this ISR FOM provides a taxonomy for the overall intelligence cycle, to include the following:

- Requirement/Concept of Operations (CONOPS) Analysis and Generation;
- Mission Planning;
- ISR Sensor Collection;
- Tasking, Processing, Exploitation and Dissemination (TPED); and
- Ground Truth.

3.8 FOM Alignment Summary

The FOMs reported in the previous sections are potential sources of standard objects and interactions. However, it is essential that first these FOMs be consistent among themselves. Here, we discuss how two of these FOMs are being, or can be aligned, to provide such consistency under an umbrella of a hypothetical SISO C4ISR FOM. This “FOM” would then provide quasi-standards, or recommended elements, that would facilitate the use of real systems in constructive, virtual, and live simulations.

The Prototype C4ISR FOM discussed in Section 3.1 provides a good starting point in discussing current and future FOM alignment. To begin with, this FOM uses the RPR FOM BaseEntity class hierarchy, with certain modifications. As shown in its Object Model Identification Table, the developers added a CommUser class, an IW Effects hierarchy, and an updated C4IDevice hierarchy, adding various attributes to existing classes and deleting extraneous ENUMERATIONS inherited from the RPR FOM. This provides a broad-based commonality for any FOM that leverages off or aligns with this C4I FOM. With a goal of general alignment among C4I FOMs, the C4I FOM developers and the J6 NETWARS FOM developers have engaged in an effort to align matching elements of these two FOMs. For example, under examination it was found that both FOMs had defined similar variables albeit not always with the same names. The following Table shows some of the observed alignment.

Prototype C4I FOM	**NETWARS FOM**
Antenna	Antenna
CommLink	Communications Link
EndUserSystem	End_System
NetworkDevice	Networking_Equipment

However, there are several cases where each FOM defines a variable not defined in the other FOM. For example, the NETWARS FOM defines the variables ATM_Device, Satellite, and Hybrid_Model which were not initially defined by the C4I FOM. Further effort on the alignment of these FOMs will be required for either of these FOMs to approach RFOM status and to fit within the umbrella of the C4ISR FOM.

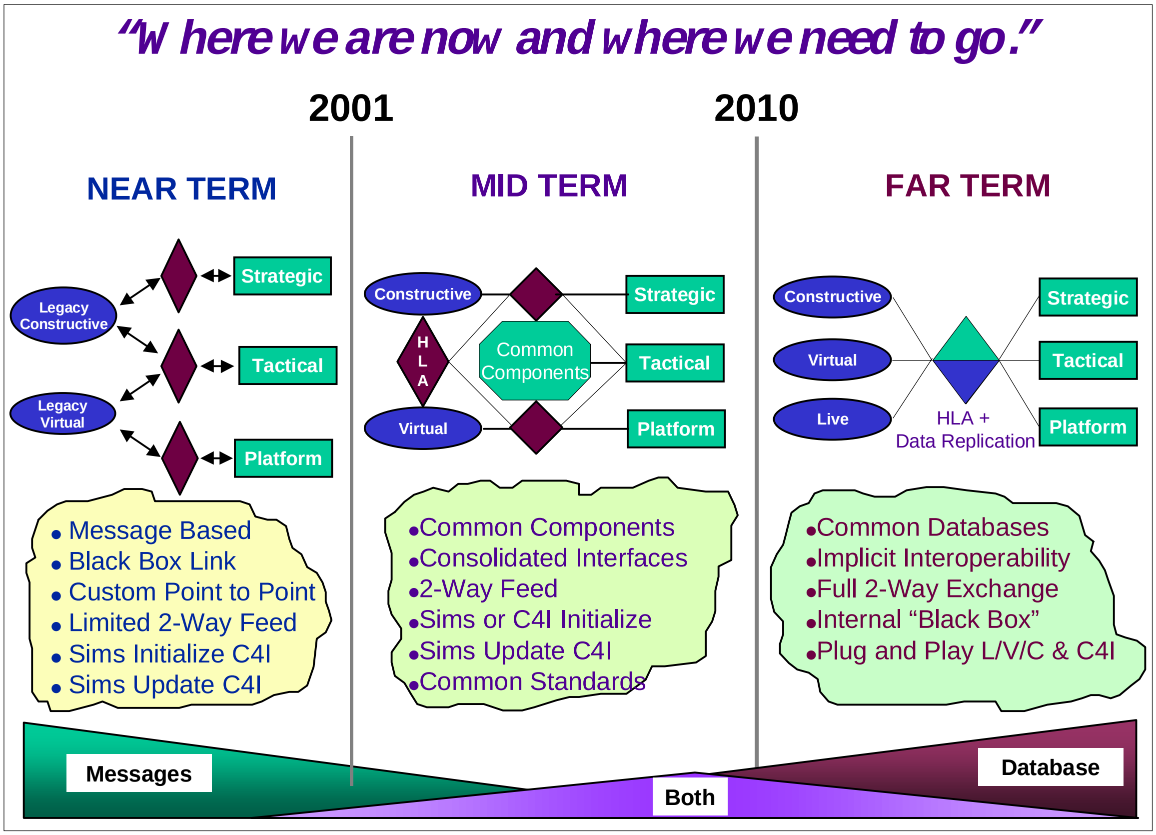

Figure 6. The Road Ahead

In summary, we have seen the beginning of FOM alignment in the collaboration of the prototype C4I FOM and NETWARS FOM developers. Lessons learned during the FOM alignment positively reinforce common design approaches, criteria, and detail. Alignment of other FOMs will increase the general applicability of the C4ISR FOM, create buy in of multiple potential FOM users and increase the FOMs critical mass required for Reference FOM status.

4. Vision

Our roadmap for improving the interoperability between simulations and C4I systems is shown in Figure 6 and our vision of an interoperable M&S-to-C4I framework is shown in Figure 7.

For the near term, Figure 6 depicts the currently predominant architectures in use for M&S-to-C4I interfaces. Such interfaces are mostly custom "point-to-point" links that are often "black box" in nature. Simulation control is basically one-way, with the simulations initializing the real C4ISR system databases.

In the mid term, we expect to see the HLA linking constructive and virtual simulations on the simulation side and, on the "real" side, the HLA, via common components found in C4ISR systems (e.g., the DII COE Common Message Processor) also allowing C4ISR systems to exchange both data and messages with simulations. Simulation initialization will be two-way, with real system databases providing information to the simulation side.

Ultimately, as shown as "*Far Term,*" we expect to have full two-way linkages via common databases, thus achieving a higher measure of interoperability. As one would expect, Figure 6 articulates only a broad vision of where M&S-to-C4ISR interoperability needs migrate to go over time. The Far Term is not an end state, but "is where we could be in 2010 to 2012, if we [*the M&S and C4ISR communities*] articulate our [*joint*] requirements and develop coordinated architectures and standards" [28].

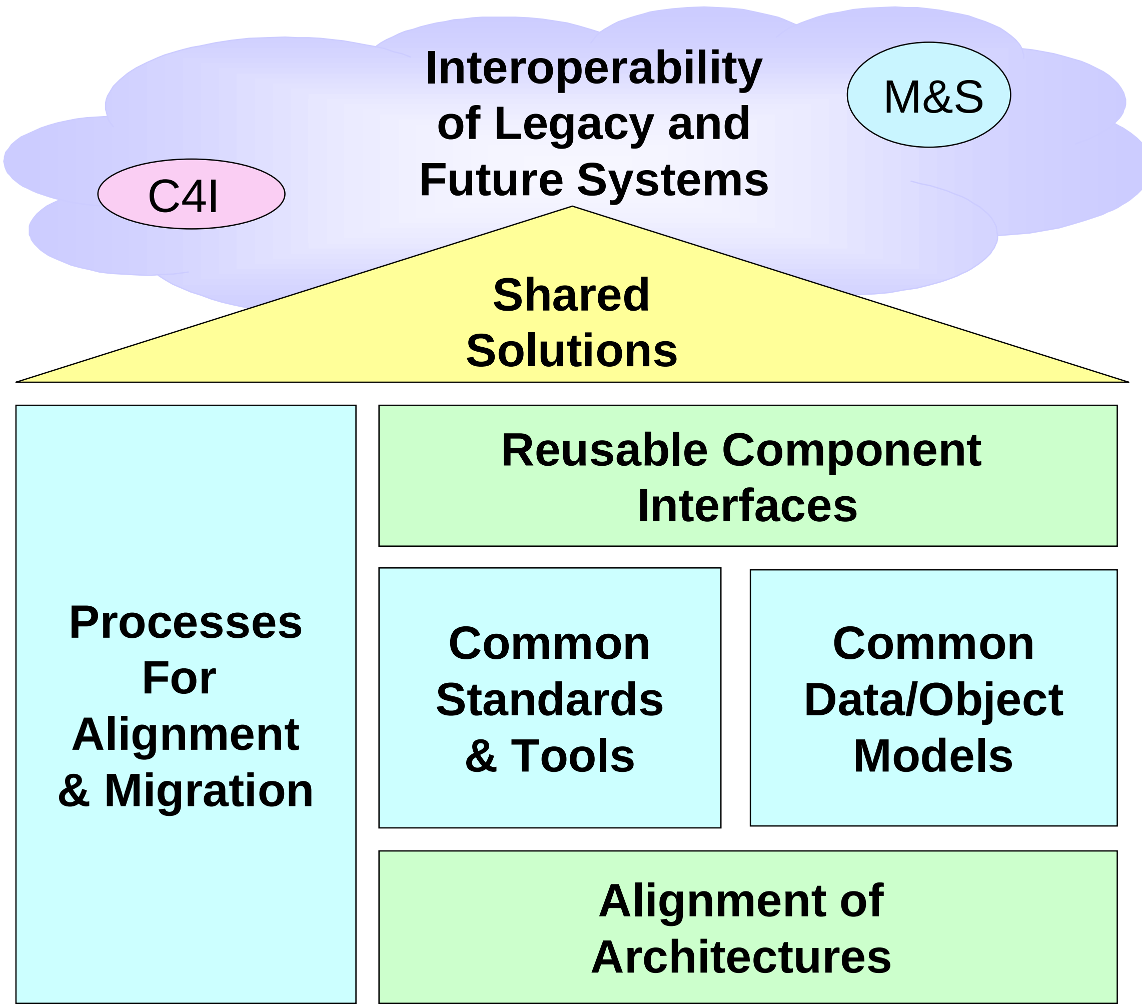

Figure 7. An Interoperable M&S and C4ISR Framework

The figure is not meant to imply that C4ISR systems have never been linked with *live* components (i.e., tanks and infantry fighting vehicles), but that it is only in the far term that we expect "to see substantial progress in constructing common interfaces to live equipment such as weapons platforms" [28].

Finally, Figure 7 depicts our vision of an interoperable M&S and C4ISR framework where interoperability is based on a common conceptual reference model accommodating common C4ISR component interfaces, common standards and tools, and aligned architectures, all linked via a common information management process to provide common, shared solutions for the C4ISR and simulation communities.

Whereas Figure 6 projects change over time and lists some of the components and elements that must result or support that change, Figure 7 focuses on the concept of a comprehensive collection of interdependent efforts that must be addressed in parallel in order to achieve interoperability.

Standards play a major role in interoperable systems and are focused primarily in the bottom three blocks of Figure 7. The SIW C4I Forum should focus its efforts on "Alignment of Architectures," "Common Data/Objects," and "Common Standards & Tools." It must be understood that a set of processes – "Processes For Alignment & Migration" – executed by both M&S and C4ISR agencies (e.g., DMSO and the Defense Information Systems Agency) must accompany the standards efforts to effect the

change required for true M&S-to-C4I interoperability.

4.1 Towards M&S-to-C4I Data Alignment and Interoperability

This sub-section presents a C4I/M&S Technical Reference Model (TRM) for a complete C4ISR to simulation interface and also functional requirements for such an interface. This discussion will set the stage for the subsequent sections, and is intended to identify the information needed when interfacing systems from the M&S and C4ISR domains.

To be specific, TRM is “a conceptual framework” that provides the following:

- A consistent set of service and interface categories and relationships used to address interoperability and open-system issues
- Conceptual entities that establish a common vocabulary to better describe, compare, and contrast systems and components
- A basis (an aid) for the identification, comparison, and selection of existing and emerging standards and their relationships [11].

4.1.1 Information Exchange Requirements

Prior to discussing specific standard software components and data models, it is desirable first to identify and classify the information that must flow between M&S and C4ISR systems. This will not be possible until there is a common understanding of what constitutes interoperability and the identification of one or more technical reference frameworks. Second, in order for M&S developers to build internal interface features that will work across a C4ISR domain (and C4ISR developers to build in M&S features) the different types of information need to be standardized to some extent. DIFs such as the Command and Control Simulation Interface Language (CCSIL) [32] need to be created for specific information classes. We identify here three broad classes that are necessary to meet conceptual requirements that would result in improved interoperability:

- Persistent Data
- Non-Persistent Data
- Execution Control

Persistent Data refers to the class of information that is stored during the operation of the simulation. Information belonging to this class is typically initialized prior to execution and changes less frequently, during simulation execution, than Non-Persistent Data.

Non-Persistent Data refers to the class of information that is transient, corresponding to interactions between entities or objects in the simulation or C4ISR database, or updates to an entity’s state.

The third class of information necessary for a complete interface is Execution Control. Simulations typically have a set of protocols that allow an operator to control the simulation’s execution and/or synchronize it with other simulations; including time management functions. Current C4ISR systems do not have protocols that correspond to information classes; however, future C4ISR systems must have such information classes/protocols to enable them to be fully interoperable with simulations.

One example of this latter class is the requirement for After Action Review (AAR). While simulations can typically replay a scenario that had previously occurred, it is often desirable to synchronize C4ISR systems with this playback to show the information available for decision making for particular events. Unless these requirements are specified to C4ISR developers, C4ISR systems may not have a capability to perform such operations.

Birkel [3] has developed a Synthetic Natural Environment (SNE) Conceptual Reference Model that is very similar to the TRM described here. It is more focused on environmental effects but still is oriented towards interfacing to C4ISR systems. It provides an excellent comparison and alternate viewpoint to the TRM. The TRM is more focused on information exchange, while the SNE Conceptual Reference Model is more focused on functionality. The SNE Conceptual Reference Model authoritatively extends the description of those classes in the TRM that deal with the

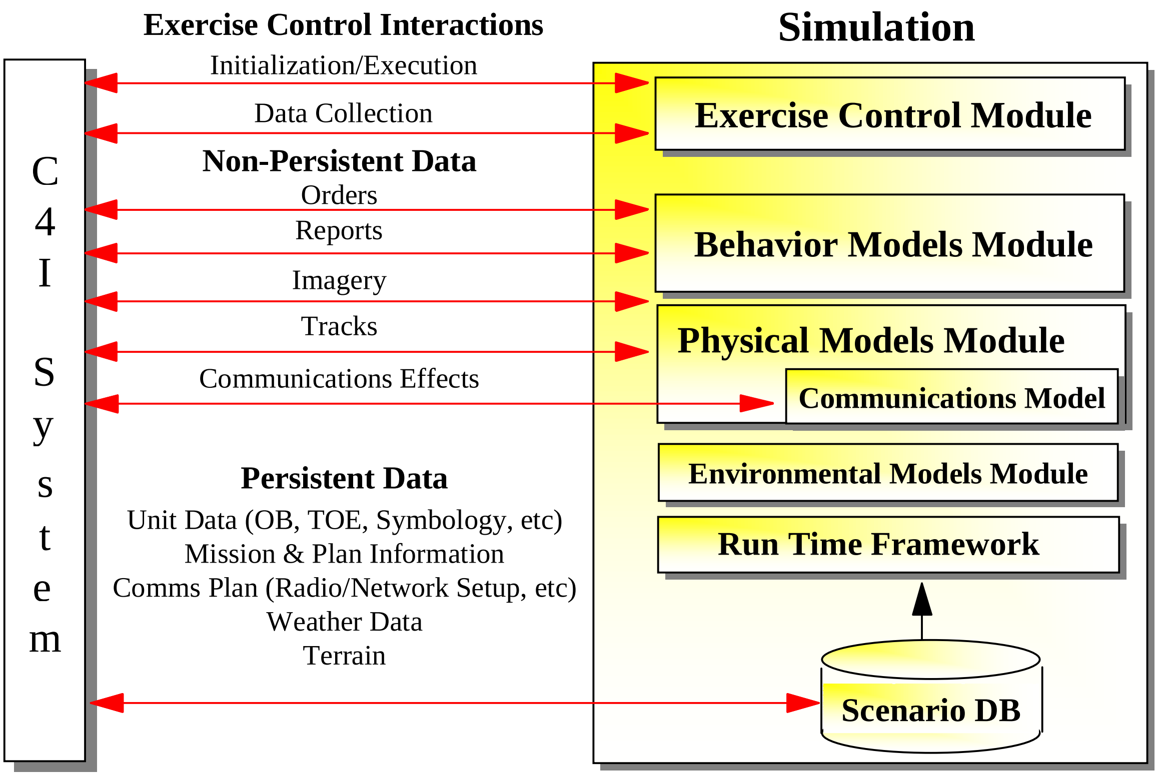

Figure 8. A C4I/M&S Technical Reference Model

environment (interfacing to physical and environmental models in the TRM).

Others have proposed models of C4I/M&S interoperability; many of those were reviewed during the development of the TRM described here. Layman [29] discusses a model of an interface for multi-level team training. This model divides information into C2, Tactical Communications, Combat Systems, and Sensors classes. These classes all fall into the Non-Persistent Data category in the proposed model. Farinacci, Roberts, and Winner [15] describe an architecture for establishing interoperability between a C4ISR system and CGF Simulation using the HLA.

4.1.2 C4I/M&S Technical Reference Model

Figure 8 shows a notional Computer Generated Forces (CGF) simulation with the types of information that a complete interface must accommodate. The interface design is not specified. The function of the interface is to 1) control the information flow between the C4ISR system and the simulations and 2) to align the information among the systems so that the information is received in a system's native format. Note that all of the information may flow bi-directionally. Thus M&S systems would need to have the capability built to accept initialization data and orders from C4ISR systems, as well as being able to pass scenario initialization data and messages to C4ISR systems.

The notional CGF can be thought of as an example of a current generation object-oriented simulation, having different modules for Exercise Control, Behaviors, Environment, and Physical Models tied together with a Run Time Framework. Persistent data is stored in a Scenario Database. Current simulations, such as ModSAF [7], can be easily mapped to this notional CGF. Each of the 12 separate information types is a candidate for a separate Reference Federation Object Model (RFOM).
Figure 8 depicts several other specific interface requirements:

- **Exercise Control Interactions** are a type of Execution Control that is passed to control the conduct of an event. The controls would allow, for example, "checkpointing" of both simulations and C4ISR systems, as well as allowing pausing of the C4ISR system at appropriate points in the exercise. Initialization and AAR protocols would also fall in this category. Exercise Control Interactions would be interfaced to an Exercise Control Module of a simulation. Logging is explicitly identified as a separate category due to the importance of this function.

- **Orders** are a type of interaction that convey C2 information. Translation of this class of information has been extremely difficult to achieve with current interfaces [4]. Presently, C4ISR systems do not support the generation and maintenance of this C2 information in a uniform manner.

- **Reports** are a type of C2 information about the state of an entity. The majority of current interfaces deal with this class of situational awareness information. Typical report information includes location and status, and may be sent to the C4ISR system as either tactical messages or data updates. Both Orders and Reports would interface to Behavior Models of a simulation, affecting the decision making of simulated units. If the simulation offers a high degree of fidelity in C2, it may associate these interactions with Communication Effects.

- **Imagery** is a type of unprocessed visual C2 information from a sensor. This data is characterized by high bandwidth requirements and the need to be processed or analyzed prior to use. Imagery would also interface to Behavior Models of a simulation, affecting the decision making of simulated units. Examples of this would be video from an Unmanned Aerial Vehicle (UAV) or a Moving Target Indicator (MTI) radar image from a Joint Surveillance and Attack Radar System (JSTARS) [56].

- **Track Data** is information regarding the physical state of entities (or objects). This class of information also includes physical interactions between objects (such as weapon effects). A simulation may need to know the location of a live unit, even if it is not sending out report messages (Reports). Alternatively, air tracks of a simulated aircraft may need to be generated for a radar screen. If the data passed to the interface is ground truth, then the data should have effects applied to turn the data into perceived truth. These interactions would be processed by the Physical Models Module of a simulation.

- **Communication Effects** (CE) emulate the characteristics of the communications channel by which the information in classes Orders and Reports are passed [6 & 42]. In most cases, a CE interaction would be paired with a C2 interaction. This interaction would be interfaced to a physical device model (such as a radio model) that transmits or receives the CE interaction, in the Physical Models of the simulation.

- **Persistent Data** covers a wide variety of information. This usually includes Order-of-Battle (OB) information as well as specification of the terrain to be used. Typically this information is not exchanged in current interfaces, but rather is manually aligned. As an example, a C4ISR system will have an OB database, and a simulation will have a completely different representation of these units. It should be possible to initialize the simulation from a C4ISR system, just as a C4ISR system should be able to be populated with exercise data from a simulation. Persistent Data would be initialized at runtime and kept current during

execution. This class of information would interface to the simulation's Scenario Database, as well as the Environmental Models Module for dynamic updates during execution. Persistent Data includes: Weather Data – essential for training exercises; Communications Laydown – needed for initializing communications networks so that communication effects can be modeled; Mission and Plan information – necessary for generation of orders; Unit Data – including the OB and associated information; and Terrain Standards. Interchange of terrain formats has been problematic within the simulation domain as well as within the C4ISR domain.

4.2 Incorporating Metadata

The proposed technical reference model identifies three broad classes of data. The lack of a fourth class of orthogonal data inhibits full interoperability. Metadata, or data about the data, is needed. The M&S community and the C4ISR users go to great lengths to certify their initial databases. Yet, as soon as interactive simulations start, data changes. Few systems today track these changes in detail. Fewer still report these changes with accompanying metadata to targeted C4ISR systems. Without metadata, subscribers cannot ensure that RTI data originates from the "correct" source within a federation. Without metadata, C4ISR systems may not be able to determine where the data entered the system and who within the system should receive it. Moreover, these systems may not be able to determine priority of the data or the very nature of the data (simulation data versus real-world information). Thus, metadata tags must record state-of-the-world information for each piece of critical data. These data items include, but are not limited to, authorized source(s), version numbers, date and time, destination, authenticated observers, etc.

4.3 LISI Model

While not explicitly developed to codify cross-domain links to M&S, the LISI model (Figure 1) provides a reasonable framework to scope the needed level of connectivity. In general, lower levels of interoperability require increased manual intervention to maintain links. However, higher levels of interoperability are not free. In general, they impose requirements for recurrent coordination between independent programs, increased levels of engineering development, and robust configuration management.

LISI identifies four domains: Procedures and Policy, Applications, Data, and Infrastructure (PAID) which impact on information exchange. As suggested in Figure 1, a level of interoperability exists within each of the PAID domains. Unfortunately, the interoperability achieved between two systems is dependent on the lowest level attained within the four domains. Thus, use of a "sneaker net" to pass information between systems of different security levels is not unusual, even though the applications, infrastructure and data may be common. This then attests to the impact of the lowest domain level and the appropriateness of considering all four domains.

Thus far, the C4I/M&S TRM focuses on data exchanges. As the LISI model suggests, this inadequately addresses interoperability between two systems. Given the LISI model was not developed to classify links between the M&S and C4ISR domains, these connections may drive extensions to the LISI metric. Potential expansion of LISI warrants further study by DMSO, in conjunction with DISA, to classify links between M&S components and standard gateways. Extension should allow the LISI model to fully capture potential connections between systems built to common standards.

4.4 Communications Interoperability

Communications is often treated separately in M&S-to-C4I interoperability. In modeling communications there is a body of expertise separate from that used for developing interfaces to C4ISR systems. In addition, many current C4ISR interfaces do not include communications considerations. In this sub-section we discuss three different aspects related to communications: 1) communications modeling; 2) communications effects; and 3)

communications content. Additional issues associated with communication interoperability include system and simulation interface anomalies (induced by the insertion of simulations into the C4ISR architecture), fidelity, and connectivity between the "real" and simulated environments (i.e., a gateway device).

Communications modeling focuses on representation of communications elements such as communications equipment, traffic, topology, and protocols. Typical uses include the assessment of measures of performance, such as latency, utilization, throughput, etc. This can be accomplished through abstractions of the information passed between C4ISR systems and networks. Often communications is not simulated in real time. Communications modeling can be performed with or without an interface to C4ISR systems and/or networks.

Communications effects focus on the environment's impact on communications traffic. For example, a radio transmission may be degraded due to propagation losses resulting from terrain and atmospheric effects. Other types of degradation include increased latency due to network loading and routing, the characteristics of the radio (i.e., bit error rate or the radio's signal to noise ratio), and interference and jamming.

Communications content of the information transaction is another consideration for communication interoperability. The spectrum of content can range from the specific size or format of the message to the actual message content. For example, message formats for tactical data link or imagery can be generated by a simulation and transmitted to a C4ISR system that would, in real life, have to process the information.

5. Recommendations

Over the last 20 years M&S and C4ISR have been linked via:

- Standard message formats;
- Message translation;
- Message parsing augmented by database mapping;
- Translation of C2 directives (e.g., Call for Fire) into simulation "orders" (CCSIL); and
- Data replication.

Obviously, better interoperability standards between M&S and C4ISR systems are necessary, but not sufficient. Both simulations and C4ISR systems must increase their functional capabilities [5]. For example, simulations must improve their reporting capabilities, and C4ISR systems must become aware of simulation constructs like exercise control.

In order to foster better understanding between the M&S and C4ISR communities, recommend that the SIW C4ISR Track collaborate with the U.S. Assistant Secretary for Defense for Command, Control, Communications, and Intelligence (ASD(C3I)) sponsored Command and Control Research and Technology Symposium to help further M&S-to-C4I interoperability and to investigate joint standards development.

In addition, develop a set of SISO M&S-to-C4I interoperability "recommended practices" and/or standards by:

- Creating a SISO M&S-to-C4I Interoperability TRM from the C4I/M&S TRM described in Section 4.1.2. This TRM should include a fourth broad data class, Metadata as described in Section 4.2 and consider the LISI model.
- Creating a SISO guide to linking M&S and C4ISR systems via standard message formats, data replication, etc.
- Using both the Prototype C4I FOM described in Section 3.1 and the J6 NETWARS FOM described in Section 3.3 as starting points, create a SISO C4I Reference FOM that provides a framework under which Base Object Models (BOM) (e.g., a radio class) can be incorporated.

6. References

[1] Anderson, J.R., Anderson, T., and Hardin, G.: "The Tactical Simulation Interface Unit (TSIU) Program," Paper 00F-SIW-

046, 2000 Fall Simulation Interoperability Workshop, 2000.

[2] Brandt, K.: "Modeling and Simulation Links with Command and Control (C2) Systems: Considerations in Architecture Design," Paper 99F-SIW-181, 1999 Fall Simulation Interoperability Workshop, 1999.

[3] Birkel, P.: "SNE Conceptual Reference Model," Paper 98F-SIW-018, 1998 Fall Simulation Interoperability Workshop, 1998.

[4] Carr, F.H. and Hieb, M.R.: "Issues and Requirements for Future C4ISR and M&S Interoperability," 7th Conference on computer Generated Forces and Behavioral Representation, 1998.

[5] Carr, F.H. and Hinton, L.G.: "Stimulating C4I Systems and Achieving Control of the Simulated Battlefield," Paper 97F-SIW-136, 1997 Fall Simulation Interoperability Workshop, 1997.

[6] Carr, F.H. and Roberts, J.D., "Incorporating Command and Control into the High Level Architecture: An Architecture for Realistic Communication Effects," Paper 97F-SIW-076, 1997 Fall Simulation Interoperability Workshop, 1997.

[7] Ceranowicz, A.: "ModSAF Capabilities," 4th Conference on Computer Generated Forces and Behavior Representation, 1994.

[8] Christopherson, T. and Dacunto, L.J.: "Simulation, Testing, Operations, Rehearsal Model (STORM)," Paper 98S-SIW-027, Spring 1998 Simulation Interoperability Workshop, 1998.

[9] Defense Information Infrastructure (DII COE) Architecture Oversight Charter, Office of the Defense Information Systems Agency, http://diicoe.disa.mil/coe/aog_twg/aog/aog_page.html, January, 1997.

[10] Department of Defense (DoD) 5000.59-P, *DoD Modeling and Simulation Master Plan*, http://www.dmso.mil/documents/policy/ msmp/index.html/, 1995.

[11] Department of Defense (DoD), *DoD Technical Reference Model Version 1.0*, Defense Information Systems Agency, 5 November 1999, http://www-trm.itsi.disa.mil.

[12] Defense Modeling and Simulation Office (DMSO) Information Paper, "Conceptual Models of the Mission Space," ftp://ftp.dmso.mil/pub/documents/initiatives/cmms/98s_siw_infoprp.pdf/, 1998.

[13] Defense Modeling and Simulation Office (DMSO) Information Paper, "Conceptual Models of the Mission Space," ftp://ftp.dmso.mil/pub/documents/initiatives/cmms/cmms_information_paper_short.pdf, 1998.

[14] Loental, D. and Leath, R.: Simulation To C4I Interface (SIMCI) Capstone Requirements Document, (Draft), TRADOC Analysis Center, 14 October 1999.

[15] Farinacci, M.l., Roberts, J.D, and Winner, B.R.: "Incorporating Command and Control into the High Level Architecture," Paper 96-15-021, 15th Workshop on the Interoperability of Distributed Interactive Simulations, 1996.

[16] Ferguson P. and Huston, G.: "Quality of Service: *Delivering Quality of Service on the Internet and in Corporate Networks*, John Wiley & Son, New Your, 1998.

[17] Flournoy, D.: "Reconciling Emerging Infrastructure Standards to Promote C2-to-Simulation Interoperability," Paper 98F-SIW-027, 1998 Fall Simulation Interoperability Workshop, 1998.

[18] Hieb, M.R. and Blalock, J.: "Data Alignment between Army C4I Databases and Army Simulations," Paper 99S-SIW-034, 1999 Spring Simulation Interoperability Workshop, 1999.

[19] Hieb, M.R., Cosby, M., Griggs, L., McKenzie, F., Tiernan, T., and Zeswitz, S.: "MRCI: Transcending Barriers between Live Systems and Simulations," Paper 97S-SIW-197, 1997 Spring Simulation Interoperability Workshop, 1997.

[20] Hieb, M.R. and Sprinkle, R.: "Simulation Infrastructure for the DII COE Architecture: The Army Vision," Paper 00F-SIW-035, 2000 Fall Simulation Interoperability Workshop, 2000.

[21] Hieb, M.R. and Staver, M.J.: "The Army's Approach to Modeling and Simulation Standards For C4I Interfaces," Paper 98F-SIW-259, 1998 Fall Simulation Interoperability Workshop, 1998.

[22] Hieb, M.R. and Timian, D.H.: "Using Army Force-on-Force Simulations to

Stimulate C4I Systems for Testing and Experimentation," Paper 1999 Command and Control Research and Technology Symposium, 1999.

[23] Johnson, T.H.: "Mission Space Model Development, Reuse, and the Conceptual Models of the Mission Space Toolset," Paper 98S-SIW-155, 1998 Spring Simulation Interoperability Workshop, 1998.

[24] Johnson, T.H. and Might R.J.: "Requirements Analysis, Mission Space Models, and the CMMS: What's This All About?," Article Fall 1999 MSIAC M&S Online Journal, http://www.msiac.dmso.mil/journal/cmms.html/, 1999.

[25] Joint Publication 1-02, *Department of Defense Dictionary of Military and Associated Terms*, June 14, 2000.

[26] Joint Technical Architecture, Versions 1.0, 2.0. 3.0, and 3.1, Defense Information Systems Agency, http://www-jta.itsi.disa.mil, 31 March 2000.

[27] Krusche, S. and Tolk, A.: "A SHADE Approach for Coupling C4I-Systems and Simulation Systems," Paper 99F-SIW-004, Fall 1999 Simulation Interoperability Workshop, 1999.

[28] Lacetera, J. and Timian, D.H.: "Interim Report Out of the C4I Study Group," Paper 00S-SIW-060, 2000 Spring Simulation Interoperability Workshop, 2000.

[29] Layman, G.E., Conover, J., Kunkel, P., and Robins, D.: "JMCIS/GCCS Interoperability with External Simulations," Paper 97S-SIW-132, 1997 Spring Simulation Interoperability Workshop, 1997.

[30] Legaspi, A.K. and Ivancic, C: "NETWARS C4ISR Communication Modeling Standard," Paper 98F-SIW-017, 2000 Fall Simulation Interoperability Workshop, 2000.

[31] Lightner, M., Schanduaa, J., Cutts, D., and Zeswitz, S.: "The High Level Architecture Command and Control Experiment – Lessons Learned in Designing an Extended Federation," Paper 98S-SIW-93, 1998 Spring Simulation Interoperability Workshop, 1997.

[32] MITRE: 1997 DARPA CFOR/CCSIL at http://ms.ie.org/cfor/, 1997.

[33] McConnell, J., Riehl, M., Hoang, T., Tafoni, T., and Lacetera, J.: "A Model for Interfacing a C4I System to Tactical Communications Simulations," Paper 00F-SIW-064, 2000 Fall Simulation Interoperability Workshop, 2000.

[34] Menzler, H.P., Krosta, U., and Pixius, K.: "HLA in a Nutshell: Proposed Standard Interface for Simulation," Paper 00S-SIW-026, 2000 Spring Simulation Interoperability Workshop, 2000.

[35] North Atlantic Treaty Organization (NATO) Document AC/323 (SGMS) D/2, *NATO Modelling and Simulation Master Plan (Version 1.0)*, http://www.dmso.mil/NATO_MSMP/ msmp, 1998

[36] Newcomb, M., Gustafson, J., and Nguyen, P.: "The WARSIM C4I Interface," Paper 99F-SIW-036, 1999 Fall Simulation Interoperability Workshop, 1999.

[37] Ogren, J.W.: "Command and Staff Training and the Practical Use of the HLA," Paper 00F-SIW-061, 2000 Fall Simulation Interoperability Workshop, 2000.

[38] Piece, J. and Wood, E.: "The TIM Suite – A Federation for Live/Virtual Simulation of C4I Systems," Paper 00F-SIW-066, 2000 Fall Simulation Interoperability Workshop, 2000.

[39] Paola, A.R. and Ressler, R.L.: "Stimulating the Army Tactical Command and Control System Using the Run Time Manager: Concepts and Implications," Paper 98S-SIW-162 1999 Spring Simulation Interoperability Workshop, 1999.

[40] Ressler, R., Hieb, M.R., and Sudnikovich, W.: "M&S/C4ISR Conceptual Reference Model," Paper 99F-SIW-060, 1999 Fall Simulation Interoperability Workshop, 1999.

[41] Shen, B., Sudnikovich, W., and Kennedy, L.: "Transition to The Objective C4I Modeling and Simulation Environment," ITSEC98, December 1998.

[42] Silva, W. Steigerwald, A., Cosby, M. Hieb, M.R., and Lacetera, J.: "Communication Emulation Design in the MRCI Program," Paper 97F-SIW-160, 1997 Fall Simulation Interoperability Workshop, 1997.

[43] Simulations Interoperability Standards Organization (SISO) Command, Control, Communications, Computers, and Intelligence (C4I) Study Group Terms of

Reference, Vision, http://www.sisostds.org/ doclib/index.cfm. August 1999.

[44] Simulations Interoperability Standards Organization (SISO) Vision, http://www.sisostds.org/doclib/doclib.cfm?SISO_FID_2383, May 5, 1999.

[45] Stanzione, T. and Chamberlain, F.: "Composable Synthetic Natural Environments for Computer Generated Forces," 7th Conference on Computer Generated Forces and Behavioral Representation, 1998.

[46] Sudnikovich, W. and Roberts, J.: "Implementation of a prototype C4I FOM: Continued Progress," Paper 99F-SIW-077, 1999 Fall Simulation Interoperability Workshop, 1999.

[47] Sudnikovich, W., Roberts, J., and Lacetera, J.: "Implementation of a prototype C4I FOM," Paper 99S-SIW-061, 1999 Spring Simulation Interoperability Workshop, 1999.

[48] Sutton, P.W.: "Interoperability Policy Roadmap," Paper 00S-SIW-157, Spring 2000 Simulation Interoperability Workshop, 2000.

[49] Thumim K., Clay, B., Hieb, M.R., and Cosby, M.: "Modular Reconfigurable Message Translation: Translation of Messages Between C4I Systems and Simulations," Paper 97F-SIW-120, 1997 Fall Simulation Interoperability Workshop, 1997.

[50] Timian, D.H.; Hicks, M.W., and Hieb, M.R.: "An Approach for Using DII COE Components to Link Simulations and C4I Systems: A Case Study Using the CMP," Paper 00F-SIW-011, 2000 Fall Simulation Interoperability Workshop, 2000.

[51] Timian, D.H., Hieb, M.R., Glass, J., and Staver, M.J.: "Using Standard C4I Components to Interface to Simulations," Paper 98F-SIW-035, 1999 Spring Simulation Interoperability Workshop, 1999.

[52] Tolk, A.: "HLA-OMT versus Traditional Data and Object Modeling – Chance or Shoehorn?," Paper 00S-SIW-024, Spring 2000 Simulation Interoperability Workshop, 2000.

[53] Tolk, A.: "Requirements for Simulation Systems when being used as Decision Support Systems," Paper 99F-SIW-002, 1999 Fall Simulation Interoperability Workshop, 1999.

[54] Tolk, A. and Schiefenbusch, K.: "Decision Support Systems – Concepts and Effects," XXXVIII. Army Operations Research Symposium, 1999.

[55] Wertman, C.: "History and Background of C4I-to-Simulation Interoperability," C4ISR Track Invited Speaker Presentation, 2000 Spring Simulation Interoperability Workshop, 2000.

[56] Williams, M.: "Proposal for Moving Target Indicator and Synthetic Aperture Radar C4I Imagery Sensor Federations for HLA," Paper 98S-SIW-019, 1998 Spring Simulation Interoperability Workshop, 1998.

[57] Yannni, P.: "A VMF/Link-16/ Simulation Gateway; Addressing the Complexity of Datalink Interoperability," Paper 99S-SIW-068, 1999 Spring Simulation Interoperability Workshop, 1999.

7. Acknowledgements

While the authors have collated submissions and edited this report, in truth it is the result of more than a dozen direct contributions in the form of draft sections and the indirect contributions of the more than one hundred subscribers to the SG-C4I reflector. Needless to say, it is impossible to thank or mention all of the individuals that contributed to this report. Nonetheless, below is list of individuals without whose contributions and efforts this report would have impossible to write:

Tonya Anderson	Andy Bowers
John Bott	Nikhil Dave
Verlynda Dobbs	Larry Dworkin
Doug Flournoy	Jerry Forbes
Zach Furness	Larry Goldberg
Carl Ivancic	Gene Layman
Bob Leath	Albert Legaspi
Dave Loental	Tom Mullins
Liesel Muth	Gary Parker
Mary Jean Rackley	John Roberts
Rick Severinghaus	Fred Smith
Ron Sprinkle	Ed Sowell
Tim Spollen	Bill Sudnikovich
Paul Sutton	Ken Sullivan
Jeff Vogel	Gary Waag